Compartment syndrome performance improvement project is associated with increased combat casualty survival

John F. Kragh, Jr., MD, James San Antonio, BBA, John W. Simmons, MD, James E. Mace, MD, Daniel J. Stinner, MD, Christopher E. White, MD, Raymond Fang, MD, James K. Aden, PhD, Joseph R. Hsu, MD, Brian J. Eastridge, MD, Donald H. Jenkins, MD, John D. Ritchie, MD, Mark O. Hardin, MD, Amber E. Ritenour, MD, Charles E. Wade, PhD, *and* **Lorne H. Blackbourne, MD,** *Houston, Texas*

BACKGROUND: In 2008, we showed that incomplete or delayed extremity fasciotomies were associated with mortality and muscle necrosis in war casualties with limb injury. Subsequently, we developed an education program focused on surgeon knowledge gaps regarding the diagnosis of compartment syndrome and prophylactic fasciotomy. The program included educational alerts, classroom training, video instruction, and a research publication. We compared casualty data before and after the program implementation to determine whether the education altered outcomes.

METHODS: Similar to the previous study, a case series was made from combat casualty medical records. Casualties were US military servicemen with fasciotomies performed in Iraq, Afghanistan, or Germany between two periods (periods 1 and 2).

RESULTS: In both periods, casualty demographics were similar. Most fasciotomies were performed to the lower leg and forearm. Period 1 had 336 casualties with 643 fasciotomies, whereas Period 2 had 268 casualties with 1,221 fasciotomies (1.9 vs. 4.6 fasciotomies per casualty, respectively; $p < 0.0001$). The mortality rate decreased in Period 2 (3%, 8 of 268 casualties) from Period 1 (8%, 26 of 336 casualties; $p = 0.0125$). Muscle excision and major amputation rates were similar in both periods ($p > 0.05$). Rates of casualties with revision fasciotomy decreased to 8% in Period 2, (22 of 268 casualties) versus 15% in Period 1 (51 of 336 casualties; $p = 0.009$).

CONCLUSION: Combat casualty care following implementation of a fasciotomy education program was associated with improved survival, higher fasciotomy rates, and fewer revisions. Because delayed fasciotomy rates were unchanged, further effort to educate providers may be indicated. (*J Trauma Acute Care Surg*. 2013;74: 259–263. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Therapeutic study, level IV.

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Posttraumatic extremity compartment syndrome in war and its surgical treatment by compartmental fasciotomy is a common, disabling, lethal, and costly problem today.[1,2] In a recent war surgery study of 337 combat casualties over 18 months, Ritenour et al.[1] reported that incomplete or delayed extremity fasciotomies were associated with high mortality and morbidity rates in casualties with limb injury. To improve combat casualty care, we fielded in 2007 an educational solution, a program that included educational alerts, classroom training, video instruction, and a research publication. The education emphasized liberal prophylactic fasciotomies in high-risk extremities and instruction of proper surgical technique of early and complete fasciotomy over delayed or revision fasciotomy for compartment syndrome. We focused the performance improvement specifically on addressing surgeon knowledge gaps regarding the diagnosis and early detection of compartment syndrome and prompt prophylactic fasciotomy. In the present study, we performed innovative scientific research by leveraging an existing database to track the outcomes of the fielded educational program to assess and then refine best practices if further education or training was needed.

The present study is an analysis comparing two periods. The first period was that of the report by Ritenour et al. in 2005 to 2006, and the second period followed in 2007 to 2009. We had access only to aggregate data from the first period, namely summary statistics including means and SDs. Thus, the secondary analysis was limited to unadjusted comparisons of the preexisting data.

The purpose of the current study was to compare casualty outcomes before and after implementation of the fasciotomy

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From the US Army Institute of Surgical Research (J.F.K., J.S.A., J.W.S., J.E.M., D.J.S., C.E.W., J.K.A., J.R.H., B.J.E., J.D.R., M.O.H., L.H.B.), Fort Sam Houston; and Department of Surgery and Center for Translational Injury Research (C.E.W.), University of Texas–Health, Houston, Texas; Uniformed Services University of the Health Sciences (J.F.K.), F. Edward Hébert School of Medicine, Bethesda, Maryland; Landstuhl Regional Medical Center (R.F.), Landstuhl, Germany; Division of Trauma, Critical Care and General Surgery (D.H.J.), Department of Surgery, Mayo Clinic, Rochester, Minnesota; and Irwin Army Community Hospital (A.E.R.), Fort Riley, Kansas.

This study was performed at Landstuhl Regional Medical Center and analyzed at the US Army Institute of Surgical Research.

Address for reprints: John F. Kragh Jr, MD, US Army Institute of Surgical Research, Damage Control Resuscitation, 3698 Chambers Pass, Bldg BHT2, Room 222-4, Fort Sam Houston, TX 78234-6315; email: john.kragh1@us.army.mil.

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education program to understand the effect of the educational program on clinical performance.

PATIENTS AND METHODS

In a similar fashion as the previous study, a retrospective review was performed of combat casualty medical records.[1] This study was conducted under a protocol reviewed and approved by the institutional review board.

The study was conducted at Landstuhl Regional Medical Center (LRMC) and the analysis at the US Army Institute of Surgical Research (USAISR). LRMC is a US military hospital in Germany to which such casualties are evacuated from theater (Afghanistan and Iraq). The study included patients who were US military combat casualties with fasciotomies in theater or LRMC. Patients were of age greater than or equal to 18 years, and detainees were excluded (Table 1). The study was conducted in two periods between January 1, 2005, through August 31, 2006, (Period 1) and April 1, 2007, through February 19, 2009 (Period 2).

A retrospective review of the registry and the paper medical charts from the patients in Period 2 was performed. In addition to routine inpatient data from LRMC, the medical records contain an initial history and data on physical examination taken on presentation to a medical treatment facility in theater, operation reports from theater, and the air evacuation request for transfer to LRMC. The retrospective review included the LRMC database of health care records for all US military casualties from theater and the Joint Theater Trauma Registry database for Injury Severity Scores (ISSs) and Abbreviated Injury Scale (AIS) scores and survival. Outcomes were rates of mortality, muscle excision, and major amputation.

The study intervention, an educational program begun in 2007 and enacted through the present, includes educational alerts, classroom training, video instruction, and a research publication (Table 2). The education emphasized prophylactic fasciotomies and instruction of proper surgical technique. The performance improvement targeted surgeon knowledge gaps on the diagnosis and early detection of compartment syndrome and prompt prophylactic fasciotomy.

Outcomes, injury patterns, and treatments were compared using Student's t test for continuous variables. χ^2 or Fisher's exact tests were used to compare categorical variables, and Student's t tests were used to compare the continuous variables. Statistical significance was determined at $p < 0.05$. Data are presented as mean (SD) or percentage of patients unless otherwise specified.

RESULTS

In both periods, casualty demographics were similar (Table 1). In both periods, most fasciotomies were performed to the lower leg (most common) and forearm (second most common).

Period 1 had 336 casualties with 643 fasciotomies, whereas Period 2 had 268 casualties with 1,221 fasciotomies (1.9 fasciotomies per casualty vs. 4.6 fasciotomies per casualty, respectively). The number of fasciotomies per casualty increased in Period 2 from Period 1 as both the number of compartments receiving fasciotomies and the number of limbs receiving fasciotomies increased. The mortality rate decreased in Period 2 (3%, 8 of 268 casualties) from Period 1 (8%, 26 of 336 casualties; $p = 0.0125$). Muscle excision and major amputation rates were similar in both periods ($p > 0.05$). Rates of

TABLE 1. Study Demographics of Period 1 Versus Period 2

Study Demographics				
	Period 1		Period 2	
Demographic	Patients (n = 336)	Percentage	Patients (n = 268)	Percentage
Age, mean (SD), y	26.5 (7.3)		26.5 (6.7)	
Sex (male/female), n (%)	332/4, 99%/1%		263/5, 98%/2%	
ISS, mean (SD)	17 (14.5)		16 (11.8)	
Mode of injury				
Explosion	288	86	207	81
Gunshot	42	12	40	16
Motor vehicle crash	10	3	7	3
Mechanism of injury				
Penetrating	258	77	203	76
Blunt	46	14	22	8
Burn	89	26	35	13
Total body surface area burn, mean (SD), %	37 (27.6)		36 (25.1)	
Inhalation injury	30	9	14	5
Abdominal compartment syndrome	13	4	2	1
Muscle excision	44	13	29	11
Major amputation	55	16	36	13
Mortality	26	8	8	3

Some data are not mutually exclusive, for example, a casualty can be burned in a vehicle crash. Some data are missing, for example, of the 268 casualties in Period 2, 254 (207 + 40 + 7 = 254) had mode of injury as listed; the proportions are thus calculated from 254, not 268, as the denominator for mode of injury. Some data, for example, mode of injury, are not mutually exclusive, for example, a crash can be associated with an explosion. Other modes in Period 2 were crush (7), fall (5), burn (5), other blunt (3), and unknown (2).

TABLE 2. Educational Program Components

Educational Program Component	Date
Alerts, clinical situations e-mailed across the trauma care system and discussed at weekly (care) and monthly (systems) global care teleconferences, minutes	April 2007
Order, All Army Action Order, Office of the US Army Surgeon General, Health Policy and Services Directorate, Complications after fasciotomy revision and delayed compartment release in combat patients	15 May 2007
Training refinements for deploying hospital personnel and surgeons	April 2007 to present
Course refinements for war surgery, fasciotomy training of surgeons and nurses (War Extremity Surgery Course, Combat Extremity Surgery Course, Joint Forces Extremity Surgery Course)	April 2007 to present
Publication of research, Ritenour et al.[1]	February 2008
Video of fasciotomy technique and compartment syndrome detection, US Army Medical Research and Materiel Command, Compartment Syndrome: Diagnosis and Surgical Management, 90-min digital video disc	2008
Guideline for clinical practice, compartment syndrome, and the role of fasciotomy in extremity war wounds, primary author J.F.K.	Drafted October 2008; approved April 2009

casualties with delayed fasciotomy were similar in both periods (6% [15 of 268 casualties] vs. 6% [20 of 336 casualties], respectively, for Period 2 and Period 1). Rates of casualties with revision fasciotomy decreased to 8% (22 of 268 casualties) in Period 2 from 15% in Period 1 (51 of 336 casualties).

When comparing outcomes between patients who underwent in-theater fasciotomies with revision and those without revision, outcomes were similar, but survival was better in Period 2 when no revision occurred (Table 3). Revision itself was associated with poor outcomes in the current study similar to the previous study. The education program was associated with no change in rates of amputation or muscle excision.

When comparing outcomes between patients who underwent early fasciotomies and those who underwent delayed fasciotomies, the same pattern of result was found as when comparing outcomes between patients who underwent in-theater fasciotomies with revision and those without revision (Table 4). Delayed fasciotomy itself was associated with poor outcomes in the current study, similar to the previous study. Outcomes were similar, but survival was better in Period 2 when early fasciotomy was performed. For the second time, the education program was associated with no change in rates of amputation or muscle excision.

When comparing outcomes between patients who underwent early fasciotomies and no revisions and patients who underwent either revision or delayed fasciotomy, the same pattern of result was found for the third time (Table 5). Outcomes were similar, but survival was better in Period 2 when early fasciotomy and no revisions were performed. Revision or delayed fasciotomy themselves had been associated with poor outcomes previously, and the same was found in the current study. For the third time, the education program was associated with no change in rates of amputation or muscle excision.

DISCUSSION

Main Findings

Education was associated with more fasciotomies, fewer revisions, and improved survival rates. The fasciotomy education program was associated with more fasciotomies per casualty indicated for fasciotomy, and the survival rates improved for casualties with fasciotomy. The rate of revision fasciotomy decreased. This set of findings indicated that after education, fasciotomies were more often complete and were infrequently short in length. Education designed specifically to encourage early and complete fasciotomy over delayed or revised fasciotomy for compartment syndrome was associated strongly with a timely and sustained improvement in survival (halved mortality rate). The education program was associated with no change in the rates of muscle excision and major

TABLE 3. Comparison of Patient Outcomes Between Patients Who Underwent In-Theater Fasciotomies With And Without Revision

Fasciotomy	Outcomes	Period 1, %	Period 2, %	Period 1, n	Period 2, n	*p*
No revision	Muscle excision	9	10	243	191	0.7385
	Amputation	16	13	243	232	0.3409
	Mortality	6	2	243	234	**0.0138**
Revision	Muscle excision	35	43	51	14	0.5959
	Amputation	24	18	51	22	0.5672
	Mortality	20	9	51	22	0.1889

n is the number of casualties in the data set in each line by period; those with data are counted and make the denominator of the fraction yielding the proportion. Period 1 data set was uniformly complete; Period 2 data set was nearly so. The statistical test is a comparison of proportions between the first two columns of data on the left which generates a *p* value. Boldface indicates $p < 0.05$.

TABLE 4. Comparison of Patient Outcomes Between Patients Who Underwent Early Fasciotomies and Those Who Underwent Delayed Fasciotomies

Fasciotomy	Outcomes	Period 1, %	Period 2, %	Period 1, n	Period 2, n	*p*
Early	Muscle excision	11	12	294	205	0.6828
	Amputation	15	13	294	254	0.5885
	Mortality	6	2	294	256	**0.0292**
Delayed	Muscle excision	25	36	22	11	0.5086
	Amputation	31	17	22	12	0.3260
	Mortality	20	17	22	12	0.8082

n is the number of casualties in the data set in each line by period; those with data are counted and make the denominator of the fraction yielding the proportion. Period 1 data set was uniformly complete; Period 2 data set was nearly so. The statistical test is a comparison of proportions between the first two columns of data on the left which generates a *p* value.

TABLE 5. Comparison of Outcomes in Patients Who Underwent Early Fasciotomies and No Revisions With Patients Who Underwent Revision or Delayed Fasciotomy

Fasciotomy	Outcomes	Period 1, %	Period 2, %	Period 1, n	Period 2, n	*p*
Early	Muscle excision	10	10	243	191	0.9856
	Amputation	16	13	243	232	0.3409
	Mortality	5	2	243	234	**0.0441**
Delayed	Muscle excision	24	40	73	25	0.1458
	Amputation	33	18	73	34	0.0724
	Mortality	19	12	73	34	0.3139

n is the number of casualties in the data set in each line by period; those with data are counted and make the denominator of the fraction yielding the proportion. Period 1 data set was uniformly complete; Period 2 data set was nearly so. The statistical test is a comparison of proportions between the first two columns of data on the left which generates a *p* value.

amputation. Although substantial and prompt improvements in care occurred, the rate of delayed fasciotomy remained the same, so efforts to increase surgeon knowledge, to research compartment syndrome, and to improve clinical performance should continue. Focus should remain on delayed fasciotomy. Although these associations are several for the attributed cause (education) and effect (improved survival), associations are not in and of themselves proof; association is not causation. For example, other care improvements such as improved resuscitation may have had a survival benefit independent of the one evidenced in the present study.

Survival rate for all US military casualties in the current war is unchanged overall at an all-time high, whereas the fasciotomy rate has increased overall with increases in limb injury severity.[2] In a recent fasciotomy study, the increased limb injury severity (AIS) made up a majority of the increase in the ISS for the casualties with limb injury at LRMC, and increased ISS routinely risks increased mortality.[2] Given the unchanged survival rate overall for the war despite increasingly severe limb injuries, evidence indicates that better lifesaving care (e.g., tourniquet use) may be one specific reason that survival is so high.[2–9] The survival benefit may be caused by less ischemia. As injury severities rise while survival remains high, improved and larger resuscitations may be associated with higher rates of morbidity such as compartment syndrome. The reason for the improved survival may have been the education, better lifesaving care, less ischemia, or other reasons, but no reason was proven or specifically excluded in the current study.

Although improvement has been made, the rate for those in most need of detection of their compartment syndrome (i.e., cases in need of delayed fasciotomy) has remained the same. Given that the rates of revision were nearly halved after the education while the delayed fasciotomy rates were unchanged, either proper detection of compartment syndrome is more difficult to teach than proper surgical technique or technique responded to the education while better detection did not. Clinical progression of limb ischemia-reperfusion syndrome may take hours or days to become detectable as compartment syndrome, which may indicate delayed fasciotomy. The reasons why casualties have delayed onset of compartment syndrome remain unclear.

The present study demonstrates that the education program was effective in that the performance improvement practitioners executed the program for which we showed how an existing clinical database was leveraged to evidence effective education. We performed innovative scientific research by tracking the outcomes of the fielded educational program to assess and then refine best practices. Some outcomes improved, and for others which stayed the same, further education or training may be needed. Perhaps, the success of the program can stimulate other proficiency-based surgical education efforts, such as those performed in simulation laboratories for prehospital, emergency department, or surgical care.

Minor Findings

Given that a fasciotomy is indicated, there evidently is a benefit to a shorter time lag to surgery so as to shorten ischemia. The fasciotomy revision rate decreased in the current study. Although the operational definition of revision remained the same throughout, the revision lag time evidently was shorter at least for several cases according to the records that were generally more complete for this detail in Period 2. Furthermore, the fasciotomy length of extension in revision was also more often detailed in Period 2 and seems to often be a shorter distance than before. In such cases, the surgeon's notes literally used the word selection of Ritenour et al., indicating that the surgeon was aware of the pertinent details of the performance improvement project. Such quality of data recording was uncommon in Period 2, but it was absent in Period 1. Together, earlier revision and smaller surgery tend to decrease both the bulk of ischemic tissue and the duration of ischemia, which tend to improve outcome, for example, survival. When records indicated the volume of myonecrosis debrided, it was less in Period 2, but the records were less consistent in describing this detail than length of fasciotomy extension. Less bulk of muscle excised would tend to improve outcome, whereas the muscle excision rate would remain the same. Given that a fasciotomy revision is indicated, there seem to be benefits to a shorter time lag to surgery and a lesser need for extension of the fasciotomy.

Study Limitations

The limitations of the present study are several. The study has a retrospective study using an existing database designed for quality improvement, and some detailed data were absent, which may have made the study more robust had such data been present. The data set from Period 1 was irretrievable except for its summary statistics. Fortunately, the sample sizes are large enough so that the central limit theorem will apply and the assumption of normality does not need to be maintained.[10]

The analysis did not indicate the relative values of the individual educational components associated with improved survival as the study was not designed to do so. Furthermore, the components were enacted serially as soon as possible; such is the nature of educational research, an imprecise science. The primary aim of the education program was to improve survival, and the secondary aim was to lessen morbidity. Evacuation can be as rapid as the day of injury for the United States if needed, but there have been efforts to delay at-risk casualties for further observation so as to detect compartment syndrome before evacuation; this practice may be more common in Period 2. The

improvement in survival for patients with complete fasciotomies may not indicate that fasciotomies themselves are specifically lifesaving in each case but that perhaps, the education program was a part of an overall improvement in predeployment education and training. Fasciotomy education and training may be a subset within all the other education and training improvements (such as damage control resuscitation, emergency surgery, burn care), which are also being successfully learned by deploying surgeons and providers. Currently, there is no practical way to separate therapeutic and prophylactic fasciotomies in a large study because the surgeons' notes inadequately differentiate them. Codes do not currently differentiate prophylactic from therapeutic procedures. Without differentiation in coding, researchers use clinical notes. However, notes are often inadequate. A coding change should be considered to differentiate therapeutic from prophylactic fasciotomy. As the delayed fasciotomy rate was unchanged, perhaps too many prophylactic fasciotomies occurred; they risk their own morbidity. The term *delayed* was used throughout the study, yet the operational definition was geographic, that is, in Germany and not in theater. However, the ischemia pathophysiology is mainly determined by duration (e.g., time in hours) irrespective of the geographic location of the casualty; geography is a practical but limited surrogate for duration.

Comparing casualty outcomes before and after implementation of the fasciotomy education program provided useful and vital information into the execution of a specific performance improvement project. Analysis of the fasciotomies performed in theater versus at Landstuhl and comparison of the data with earlier data from the war helped us to understand the effect of the educational program on clinical performance. In addition, the information from this study advances the overall knowledge of fasciotomies, particularly for educators of surgical technique and leaders of large trauma systems. The program was a success because more fasciotomies were performed, and survival improved (mortality rate was halved). Revision fasciotomy rates also improved, but rates of muscle excision, amputation, and delayed fasciotomy remained the same. Information gained from this study may benefit both soldiers and civilians, and future refinements in education and training are indicated to improve clinical performance and outcomes.

AUTHORSHIP

J.F.K., J.S.A., C.E. White, J.R.H., B.J.E., J.D.R., M.O.H., A.E.R., C.E. Wade, and L.H.B. designed this study. J.F.K., D.J.S., C.E. White, J.R.H., B.J.E., D.H.J., and A.E.R. conducted the literature search. J.W.S., J.E.M., D.J.S., R.F., J.D.R., M.O.H., and A.E.R. collected data, which all authors participated in interpreting. All authors contributed to the writing of the article.

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